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INTERNATIONAL AVIATION

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GOLD-BASE ALLOYS FOR USE IN AVIATION INSTRUMENTS

Ho An-li and Tang Dao-kun

One

In current aviation instruments, such as artificial horizons, autopilots, flight direction indicators, and so on, all of which are instruments which depend on gyroscopes in one way or another, principal use is made of alloys based on silver, gold, palladium and platinum as the materials for the manufacture of important electrical contact components for use with small power electrical outputs, signals, sensors, and so on. In order to guarantee that these types of instruments, through the entire process of their use, will be capable of putting out a stable and accurate electrical signal, it is required that the materials in the electrical contacts have capabilities in many areas. Besides the requirement which there is for these materials to be possessed of certain mechanical characteristics or capabilities as well as excellent electrical and physical capabilities, an even more important requirement for these materials is that they have excellent chemical and electrochemical capabilities, that is to say that these materials must have : 1 - excellent chemical stability so that they will not be susceptible to deterioration due to the surrounding air and the actions of such forces as oxidation, chemical combination with sulfur, corrosion due to salt vapors, humidity, temperature, and so on; 2 - good capability for resistance to contamination from the organic gasses in the atmosphere which are the results of pollution; and, 3 - these materials must not be prone to the easy production of sparks and the damage which comes from sparking or to arcing or to metallic transferance, and so on, and they must have a relatively strong resistance to corrosion which impedes the flow of electricity.

In response to the development of the technology associated with instrumentation and electronics, the various nations of the world have each produced test samples of various types of materials which form part of a new series of substances for use as electrical contacts. However, it can be seen that the test production of these new materials has already passed beyond the satisfying of the general run of requirements for physical capabilities, and it is more and more giving its greatest attention to functional capabilities; this emphasis is most particularly directed toward research in the area of the functional capabilities of electrical contacts.

Two

The beginning of the test production of these materials for use as electrical contacts in aviation instruments began relatively late in our country. From the decade of the 1950's to the beginning of the 1960's, far and away the largest part of the materials which were used as electrical contacts for aviation instruments were alloys based on platinum and palladium; not only were these materials extremely high in price, but they made China reliant on imports of foreign materials, and, even more important, there were serious shortcomings in the area of the capabilities of these materials in their roles as electrical contacts, and these shortcomings affected the quality of the output of the instruments in which they were used. For example, in the process of the production and use of these materials, it was a common occurrence to see cases of unreliable electrical contact between contact components, and in extreme cases, the effectiveness of these electrical contact components was lost entirely. Observation and analysis demonstrated that the phenomenon of the unreliability of this type of contact was mostly due to the appearance on the surface of the contacts of a dark brown-colored granular powdery sediment material. After putting this material through analysis, it was discovered that it was the result of organic pollutants. In aviation instruments, there are large amounts of plastics, rubber insulating materials, sealing materials as well as paint and so on, and all of these materials are organic; under certain conditions of temperature, these materials are capable of putting out organic vapors, and, when these vapors are absorbed into the surface of the metallic materials which we have been discussing, there occurs, under operational conditions, the formation of friction compounds due to the friction of movement between the contact components involved, and these compounds are what we have called more normally the "brown-colored powder." This powder is nothing else than a pollution of the platinum and palladium based alloys by the organic vapors which we have been discussing. Even though the reasons for the formation of these types of pollutants are still under continuous investigation, it is generally recognized that there is a relationship between the formation of these pollutants and the fact that platinum type metals belong to the family of the transitional elements. The *a* level of the family of transitional elements is short of electrons, and this condition makes it easy to give rise to a catalytic action which is adequate to cause the organic hydrocarbons to enter into compound and form the sediment which we have been discussing; because of this fact, platinum and palladium, which belong to the transitional elements family as well as the alloys which are based on them are very easily made to accept organic pollutants, and this is a shortcoming of this type of element. Given this situation, it is only gold which is possessed of the capability for excellent resistance to contamination from the sort of organic pollutants which we have just been talking about; gold does not give rise to "brown-colored powder" compounds, and the use of gold-based alloys as materials for electrical contacts is safe and reliable. Due to the facts that gold and its alloys are not only cheap in price when compared to the alternatives but also have excellent capabilities, these types of alloys have received very general attention from people in recent years.

Table 1 sets out a comparison of the relative capabilities of gold and its alloys and the capabilities of platinum family metals to resist organic pollution.

In order to improve the quality of our Chinese aviation instruments, and to make the materials necessary for these instruments available from within the range of materials which China is capable of producing herself, beginning in the middle of the 1960's, the appropriate government agencies within China began the test production of electrical contact materials which are made from gold and its alloys. After going through more than ten years of unceasing test production and utilization, the advantages of gold-based alloys are appearing in more and more obvious ways, and, in aviation instrument applications, they are already gradually taking the place of materials made from alloys of platinum and palladium. Table 2 sets out the chemical formulae or names and the principal characteristics of some of these gold-based alloys.

Three

Gold-based alloys are used in aviation instruments in the roles of electric brushes, coils, current conducting plates, potential coils, sliding contacts, center contacts, multi-directional plates and various other similar kinds of electrical contact components; the principal reason for gold-based alloys having attained to this kind of widespread use is the overall excellence of their characteristics or capabilities.

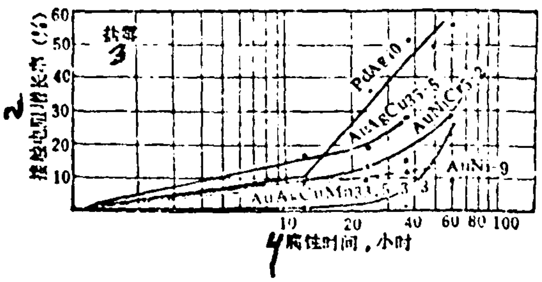
The electrical characteristics or capabilities of gold-based alloys are excellent, and this excellence appears primarily in the form of the fact that it is possible, through the addition of different kinds of alloying elements such as Ag, Pd, Cr, Mn, Fe, Al, and so on, to alter the rate of electrical resistance of the alloy produced; this alteration of resistance can

Table 1

A Comparison of the Situations or Characteristics of Au, Pt and Pd as well as Other Metals of a Similar Sort and Their Alloys from the Point of View of the Problem of the Formation of "Brown Powder" on Sliding Contacts.

2 接点材料	3 配合材料	4 生成"褐粉"比率
Pt	Pt	100%
Pd	Pd	95%
Ru	Ru	55%
AuAgPt26-7	Pd	50%
AuAg30	Pd	20%
AuAgPt26-7	AuAgPt26-7	12%
Ag	Ag	0
Au	Au	0

Key: 2. Contact Material, 3. Alloying Material, 4. The Rate of Production of "Brown Powder."



① 气氛浓度，NaCl3%，每小时喷射15分钟

② 相对湿度，98%

③ 环境温度，30°C

Figure 1. The Relationship Between Duration and Increase in the Rate of Contact Resistance After the Alloys Go Through a Salt Vapor and Humidity Corrosion Test. The Test Conditions were: 1 Atmospheric Concentration: Na Cl 3%, Sprayed in for 15 Seconds Every Hour, 2 Corresponding Humidity: 98%, 3 Ambient Temperature 30° C, 2. Rate of Increase of Contact Resistance (%), 3. Salt Vapor, 4. Corrosion Duration, Hours.

cover the range from 0.10 to 2.0 Ohms cm^2/m, and it is thus possible to satisfy the operational requirements of instruments for a full range of resistances from low to high. The temperature coefficient of resistance for these alloys is capable of reaching as low as approximately zero, and this is a characteristic which platinum-based alloys have a great deal of difficulty in matching.

Table 2 Characteristics or Properties of Gold-Based Alloys

2 序号	3 合金	比重 4 克/厘米³	电阻率 5 ρ(20°C) Ω·毫米²/米	电阻温度系数 6 1×10⁻⁴/°C (0~100°C)	对Cu热电势,毫伏/°C 7		抗拉强度 σ_b 8 公斤/毫米²	显微硬度 H_D 9 公斤/毫米²	弹性模量 E 10 公斤/毫米²
					0~+151°C	0~−76°C			
1	AuAgCuMn 33.5-3-3	14.1	0.24~0.26	1.98	−0.0014	+0.00188	70~95	190~230	8250
2	AuNiCr 5-1	18.67	0.24~0.26	0.416			65~75	160~207	
3	AuNiCr 5-2	17.4	0.38~0.42	1.11	−0.0266	+0.0193	70~95	190~230	8550
4	AuNiFeZr 5-1.5-0.3	18.2	0.41~0.48	2.5~2.7			80~95	230~250	8300
5	AuNi9	17.3	0.19	5.9	−0.0525	+0.0415	78~95	230~270	9300
6	AuCuNiZn 22-2.5-1	14.7	0.19	4.4	−0.0127		90~110	240~290	11000
7	AuNiCu 7.5-1.5	17.4	0.19	6.10			65~85	200~280	8550
8	AuAgCu 35-5	14.2	0.12	6.86	−0.00206	+0.00230	80~95	170~220	8450

Key: 2. Sequence Number, 3. Alloy, 4. Specific Gravity in Grams/cm^3, 5. Rate of electrical Resistance in Ohms cm^2/m, 6. Temperature Coefficient of Electrical Resistance, 7. The Thermoelectrical Reaction with Cu in Millivolts/C°, 8. Tensile Strength in kg/cm^2, 9. Microhardness in kg/cm^2, 10. Modulus of Elasticity in kg/cm^2.

Gold alloys are possessed of definite mechanical properties or characteristics as well as extremely good mechanical working properties. If this basic material undergoes the addition of Ag, Pt, Cu and Ni as well as the addition of extremely small amounts of the rare earth elements, then, it is possible, on a rather large scale, to adjust the strength and hardness values for these materials, and this is done in order to guarantee the

the structural strenght, elasticity and useful life of instrument componets. With gold-based alloys it is possible to manufacture extremely fine wire by a pulling process; it is also possible, with this type of material, to make extremely thin plates by a pressure rolling process, and this sort of material is also capable of being formed into quite complicated or complex forms of material by the use of impulse pressure.

Alloys which are based on gold have one very singular advantage, and this advantage is excellent chemical stability. Not only does this refer to the normal type of good capability for resisting corrosion from acids and salts, even more importantly, it refers to a strong ability to resist corrosion due to the surrounding atmosphere, that is to say that it refers to the ability of gold-based alloys which are acting in the role of electrical contact components in a corrosive surrounding atmosphere to maintain, despite this sort of environment, a low and stable resistance in those electrical contacts which quality will cause those contacts to be constantly reliable; these sorts of qualities and this sort of reliability are precisely the type of operating characteristics which are most especially required in the materials used in aviation instruments. The capability for resisting corrosion due to the atmospher~~e~~ic environment, about which we have been talking, refers to the possession by gold-based alloys of the ability to resist corrosion due to the problems of oxidation, chemical combination with sulfur compounds, salt vapor, humidity, organic gasses and so on, all of which are found in industrial atmospheric environments and oceanic atmospheres. As far as other alloys are concerned, all of them have certain problems when it comes to the ability to resist corrosion from various types of gasses or atmospheres, for example, some alloys, after they pass through a certain type of corrosive gas mixture, exhibit changes in the condition of their surfaces, or they exhibit changes in color, or their surfaces give rise to certain types of thin films, or their surfaces absorb certain types of harmful gasses or substances, and some other alloys do not exhibit any of these characteristics. However, these types of changes in the surfaces of these substances can have an influence on the signal outputs of electrical contact components. If we use a method for determining the magnitude of the change in the static electrical resistance before and after the corrosion of an alloy, then, it becomes possible to distinguish the good and bad characteristics of certain alloys in the area of resistance to corrosion by the surrounding atmosphere. The larger is the change in the rate of increase of the electrical contact resistance, the larger then is the inadequacy of the alloy concerned in terms of its ability to resist corrosion, and, necessarily, the less adequate is the reliability of electrical contacts which may be made from such a material. The original electrical contact resistances for gold-based alloys, platinum

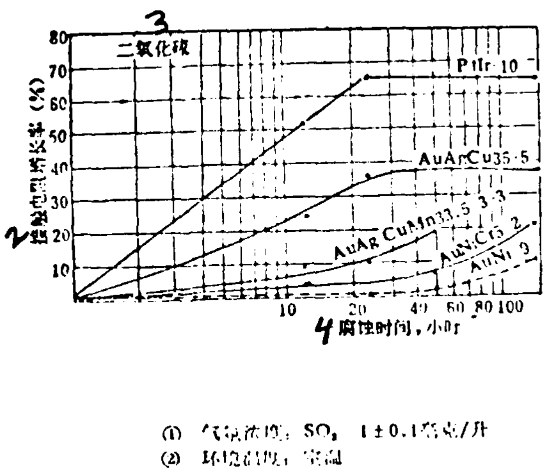
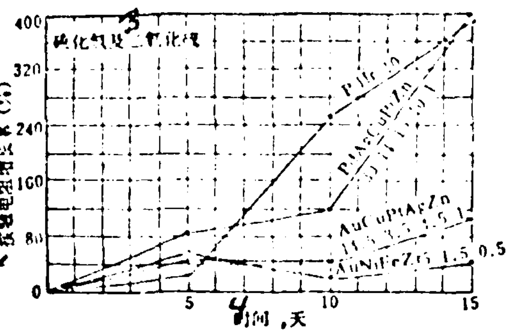


Figure 2. The Relationship Between Time and the Rate of Increase of Electrical Resistance After Alloys Undergo Experiments with Corrosion by Sulfer Dioxide. Experimental Conditions: (1) Gaseous Concentration: SO_2 1 ± 0.1 mg/l (2) Ambient Temperature: Room Temperature, 2. Rate of Increase of Contact Resistance 3. Sulfur Dioxide, 4. Corrosion Time in Hours.



① 气体浓度：H_2S 100PPM
SO_2 700PPM
② 相对湿度：80～85%
③ 试验温度：常温

Figure 3. The Relationship Between Time Duration and Rate of Increase in Contact Resistance After Alloys Undergo Experimentation with Corrosion by H_2S and SO_2 Experimental Conditions: 1 Gaseous Concentrations: H_2S 100 PPM SO_2 700 PPM 2 Relative Humidity: 80-85% 3 Experimental Temp: Standard Temperature, 2. Rate of Increase in Contact Resistance (%), 3. Hydrogen Sulfide and Sulfur Dioxide, 4. Duration in Days.

based alloys and palladium based alloys before corrosion are layed out in Table 3; the changes in the rates of increase of contact resistance for the various kinds of alloys after they have undergone the various types of gaseous corrosion are as shown in Figure 1, 2, 3 and 4.

From the data in Table 3 and Figures 1, 2, 3 and 4, we can clearly see that the electrical contact resistances for gold-based alloys are universally smaller than the electrical resistances for alloys based on platinum and palladium; this was particularly true for the instances in which the resistance values for the materials themselves (discounting corrosion) were closely approached; this is an extremely valuable property in a material if one is dealing with electrical contact components which handle weak signals at small power outputs. After going through the process of corrosion by combination with sulfur and

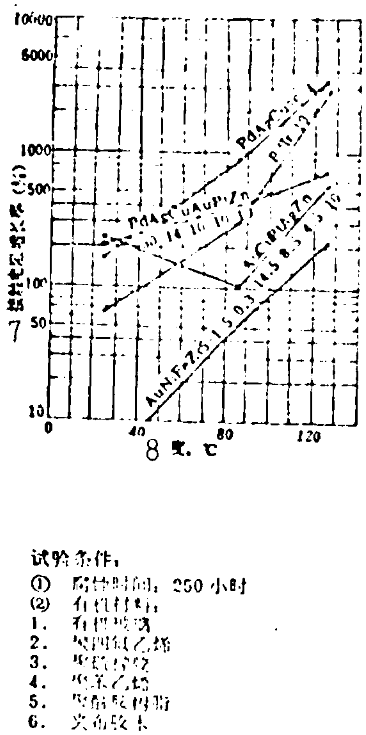


Figure 4. The Relationship Between Temperature and the Rate of Increase of Contact Resistance After Alloys Undergo 250 Hours of Testing for Corrosion by Organic Vapors Test Conditions: (1) Corrosion Time: 250 Hours (2) Organic Materials 1. Organic Glass, 2. A Compound of Ethylene and Flourine, 3. A Compound of Sulfur and Rubber, 4. Polystyrene, 5. Polyethylene, 6. A Type of Gum Resin , 7 contact resistance, 8 temperature.

salt vapor, the change in the electrical contact resistance of contacts made from alloys which are based on gold was smaller than the corresponding changes which took place in electrical contact components which were made from materials consisting of alloys based on platinum and palladium; this was most particularly true after the alloys had undergone corrosion by organic gasses; in such a case, the rate of increase in electrical contact resistance for the gold-based alloys was much, much lower than the corresponding rates for alloys based on platinum and palladium. It is also true that, after the alloys had been through 250 hours of corrosion by organic gasses at conditions of 125°C, the surface of the alloy based on gold was basically unchanged in color while the surfaces of the alloys which were

Table 3. Electrical Contact Resistance of Alloys

合金牌号	电阻率 (ρ) Ω·毫米²/米	接触电阻 Ω
AuAgCu 35-5	0.12	0.015~0.016
AuAgCuMn 33.5-3-3	0.21~0.26	0.03~0.04
AuNiCr 5-2	0.38~0.42	0.053~0.058
AuNiCu 7.5-1.5	0.30	0.0318
AuNi9	0.10	0.031~0.034
PtIr10	0.245	0.042~0.051
PdAg40	0.42	0.0027
PtIr17.5	0.28	0.0522
PtNi5	0.228	0.062
PdIr18	0.351	0.043

Key: 2. Alloy Names or Symbols, 3. Rate of Electrical Resistance in Ohms cm^2/m, 4. Electrical Contact Resistance.

based on platinum and palladium had already turned a "brown color." All these results explain why the electrical contact characteristics of alloys based on gold are very much better than the corresponding characteristics for alloys based on platinum and palladium.

Four

In the last ten or fifteen years, our Chinese gold-based alloys have enjoyed a considerable development; all together, we have made test production of a score or more of alloys, and through experimentation in the use of these alloys in aviation instruments, we have obtained very satisfactory results. At present these alloys have already formed part of our body of Chinese alloys. In the period between the end of the 1960's and the beginning of the 1970's, these types of gold-based alloys have already replaced the largest part of platinum and palladium-based alloys which were used in aviation instruments. At the same time, these new types of alloys are also spreading out their influence into the areas of space technology, electronics and other industrial disciplines. The utilization of these gold-based alloys has opened up a new vista in the area of materials for electrical contacts for aviation instruments in China. The employment of these new materials has raised the quality of our aviation instruments, and the phenomena of unreliability which used to appear routinely in the performance of aviation instruments in the past have now been very clearly improved. The use of alloys based on gold has reduced the shortcomings which were associated with alloys based on platinum and palladium, that is, the problem of the great expense involved in getting these materials as well as the problem that they had to be imported from sources outside China; the use of gold-based electrical contact materials makes it possible to depend only on resources which can be obtained only within China, and this has a definite strategic significance.

As the development of aviation instruments advances in the direction of "electronicization", miniaturization, high precision and long life, there is a requirement for a systemization of the numerous types of alloy formulas which are currently in existence and a standardization of this variety; at the same time, there is a need for systematic research in the area of strengthening or heightening certain special characteristics of the alloys based on gold. For example, how can we lessen the coefficient of friction for the gold-based alloys under conditions of low pressure and, thereby, guarantee the high sensitivity and high precision of the instruments involved, and how can we employ the research which we promote into the area of friction losses in these types of materials as well as into their matching and so on in order to increase the anti-friction characteristics of these materials and, thereby, guarantee a long life for the instruments involved?

In recent years, there have appeared, in the area of the gold-based alloys, composite materials which are formed by the addition of minute quantities of the rare elements and the inclusion of self-lubricating substances; both these methods of producing these composite materials and these new materials themselves are effective in the reduction of the coefficient of friction and the extension of the friction-resistant life of the instruments involved. Without doubt, in the future, there should be carried out, in the area of the alloys based on gold, even broader and more systematic research into these areas as well as the related aspects of surface physics, surface chemistry, the study of friction, and so on; this sort of research effort will be useful in causing the gold-based alloys and their applications to make even newer contributions and accomplishments.

FERROUS METALLIC GLASS

Chen Shi-quing

Any type of fluid, if its speed of cooling is sufficiently great, is capable of turning into a glass-type state or condition. Generally speaking, compound fluids such as silicate and polymethylate, for example, due to their large viscosities and slow rates of crystalization, find it easy to be formed into glass. Metals are definitely different from the case of the materials mentioned above. Due to the fact that their viscosity is small and they crystallize exceptionally rapidly, they find it much easier to turn into crystals. When use is made of the high-speed vapor method to turn them into powders, and their speeds of cooling reach 10° C/sec, these substances still remain crystals, albeit these are branch crystals whose axial distances are very small, that is, in the neighborhood of 5 mm. If one is dealing with a situation in which the speed of cooling is sufficiently large, that is, $10^8 - 10^{10}$ C/sec, for example, then, in such a case, these metals will no longer form crystals. They will form glass, and these sorts of glasses are called metallic glasses.

In 1972, this super-fast cooling method was used to obtain ferrour metallic glass ribbons, and this event opened up a new realm in ferrous metallurgy. Of course, there had been ferrous metallic glass in existence before this time, but, due to the defect of inadequate plasticity, it had no useful value.

As soon as this type of metallic glass appeared, it caused widespread attention in many areas. This attention was due to the fact that this new type of glass possessed such qualities as high strength, a high resistance to erosion or wear, a high rate of electrical resistance; it is easy to magnetize; its rate of attenuation in super-sonic applications is low; it is also true that it is easy to work with technically speaking, and so on.

In ferrous metallic glass, the constituents, stated in their simplest form, are two basic substances melted together, for example, Fe-B, Fe-C and Fe-P. Normally, other elements are added in order to satisfy special requirements. For example, one would add nickel to improve the plasticity of the glass; one would add molybdenum to increase the strength of the glass, and one would add cobalt to make it easier to magnetize. Of course, the components of this type of metallic glass are not the same as those of ordinary steel. The amount of compounds contained in this type of metallic substance is relatively higher (see Table 1). There are also obvious differences in molecular structure between this type of metallic glass and crystalline metals.

THE PRODUCTION OF METALLIC GLASS

If one takes a thin flow of molten alloy and sprays it onto a cold revolving wheel, then it is only necessary for the conditions to be right, and strip shapes or ribbons of the metallic glass will be formed by the dispersion which follows the collision between the fluid alloy and the wheel. At present, it is already possible to make continuous production of ribbons of ferrous metallic glass which have lengths which are figured in miles. The rate of speed for this sort of production can reach 450-1800 m/min; the width of the ribbon is from 75 mm - 50 cm, and the width of the ribbon is from 25 mm - 130 mm.

Because of the fact that it is necessary to carry out superfast cooling, heat is dissipated quickly. Because of this fact, the semi-manufactured product has one dimension which is very small, generally 0.25 cm or less. In this sort of situation, it is only possible to produce by the use of spraying powder, wire, ribbons, thin plates, and thin shells or casings; it is not possible to form semi-finished goods which have volume to them.

Ferrous metallic glasses, at room temperature, are stable. If one adds heat to the glass until it reaches the temperature at which it changes, then the energy of atomic activity is increased, and, if one increases the temperature a bit again, the substance loses the lustre of glass, and turns into a crystalline material.

THE RELATIVE ADJUSTMENT OF STRENGTH, PLASTICITY, AND FLEXIBILITY

The bending strength of ferrous metallic glass is very high. It has such a high value that the general run of steels cannot match it; only particular special steels can be compared to it (see Table 1). For example, $Fe_{80}B_{20}$ metallic glass has a bending strength which exceeds 525,000 lbs/in^2; this material possesses a high hardness value (HV = 1100), and it is resistant to corrosion. The strengths of some glasses are even higher than this, for example, Fe_{75} B_{26} has a hardness value of HV = 1300 and a bending strength which is 575,000 lbs/in^2.

The strength of silicon glass is high, and its density is low. However, due to a deficiency in plasticity, its resistance to blast and blast errosion has a very low strength rating. It is best to make use of fracture flexibility in order to measure the degree of blast or shock strength. From the data which appear in Table 1, it is possible to clearly see that the fracture flexibility of ferrous metallic glass is much, much greater than that for silicon glass.

Figure 1 sets out the relationship between the fracture flexibility and the bending strength. An obvious feature of these data is that, when the bending strength reaches 525,000 lb/in^2, the fracture flexibility K_{10} is approximately 11,000 lb/in^2 $\sqrt{\text{in}}$; when there is a tearing of the material, then the K_{48} is approximately 42,000 lb/in^2 $\sqrt{\text{in}}$. If one is considering the case of high strength steel, then, at the same level of bending strength, the facture flexibility is almost zero.

One of the special features of metallic glasses is that it is possible to make them with dual directional bending strengths which surpass 500,000 lb/in^2 when the material is in ribbon form. Moreover, the general run of high strength parallel fiber arrangements which go to form ribbon-type materials have high values only for a single direction; multi-crystalline materials only achieve high strengths in the direction of a rolling pressure. Dual-directional high strength ribbon materials, as far as composite material structure designs are concerned, have the advantages which are listed below:

1. They are easy to roll up. Ribbon materials can be rolled up much faster than wire-type materials can be.

2. This kind of material has a high packing rate. The highest packing rate for wire-type material is 91%, but, for ribbon material it is 100%.

3. This sort of material has a large corresponding caking force (caking strength). Under conditions in which the strengths and horizontal cross sectional area are equal, the caking strength of the ribbon-type material is far greater than the caking force of wire-type material; this is due to the fact that the former has a circumference which is much, much larger than that of the latter.

Table 1. A Comparison of the Characteristics or Properties of Ferrous Metallic Glass, Steel, and Silicon Glass

材 2 料	3 屈服强度 千磅/英寸²	4 断裂韧性 K_{IC}, 千磅/英寸²√英寸
5 金属玻璃		
Fe[illegible]Ni[illegible]P[illegible]B[illegible]	350	8.5
Fe[illegible]B[illegible]Si[illegible]	350	—
Fe[illegible]B[illegible]	525	11
Fe[illegible]Cr[illegible]Mo[illegible]B[illegible]	650	—
6 钢的[illegible]		
32号冷[illegible]钢 7	200	—
AISI 4340	210	30
8 [illegible] 18% Ni	290	35
9 轮胎钢丝帘布(0.9%C)	400	—
10 硅酸盐玻璃		
E-玻璃 11	500	0.3

Key: 2. Material, 3. Bending Strength in 1000 lbs/in^2, 4. Fracture Flexibility K_{1C} in 1000 lbs/in^2 in., 5. Metallic Glass, 6. The General Run of Steel, 7. Type 32 Cold Steel, 8, 18% Nickel Which Takes Care of the Heat of Deformation, 9. Rolled Steel Wire, 10. Silicate Glass, 11. Glass.

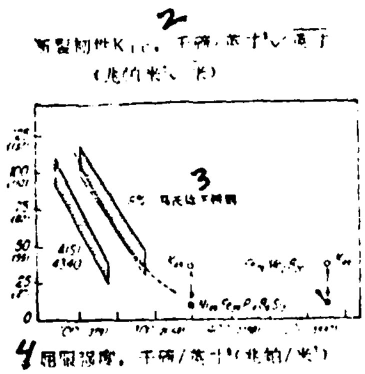


Figure 1. The Fracture Flexibilities of Metallic Glass and High Strength Steel, 2. Fracture Flexibility K_{1C}, 1000 lbs/in^2 in (a million [illegible] m^2 m), 3. Martensite Steel (illegible), 4. Bending Strength in 1000 lbs/in^2.

4. The stress concentration for this type of material is small. When this type of material is used as a strengthening material, and under circumstances in which the quantities involved are fixed, then, thin ribbon-type material is capable of being rolled up in such a way that the side stress concentration is relatively smaller than that for wire-type materials. Moreover, the small surface cracks which are produced by stress concentration do not easily spread in the direction of neighboring ribbons.

5. This sort of material has a high shear force rigidity. Ferrous glass ribbons are capable of resisting shear forces which are applied parallel to its edges, and it possesses the rigidity of steel. There is almost no difference between single direction fiber-strengthened ribbons, and their shear strengths and compound-based materials. This type of shear force strength, as is found in metallic glass (if we add the conditions that both the circumference and the cross sectional area are relatively larger), is capable of causing the shear force strength of the basic body and the strength of the ribbon-type material to correspond, and, as a result of this, it is possible to obtain a composite material with optimum characteristics.

6. This sort of material has a great capability to resist penetration. Wire type materials are easily opened up by penetrating objects; ribbon-type materials are not (this is true when the dimensions of the penetrating object are equal to or smaller than the width of the ribbon.)

7. This sort of material has a great resistance to shock or blast and to being cut. The plasticity of the metallic glasses causes them to be capable of absorbing shock or blast energy by means of this plasticity; this capability for resisting shock or blast can be expressed by the measurement of the amount of the fracture flexibility.

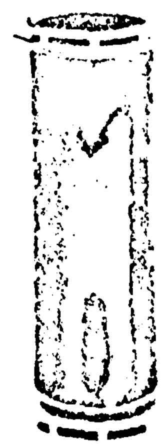


Figure 2. Metallic glass tube.

The structure of the metallic glasses makes it possible to weave them into cloth and form them into tubes. If one takes the glass ribbons and spreads them out in a parallel way and an orthogonal way, or if one folds them up in a rotating way, then, it is possible to form them into tube or barrel shapes, as well. These semi-finished goods can be used as electrical insulation or covers, the axis of rotation for a torsion moment, a pressure vessel, a flywheel, a conveyor belt, the protective shell of a rocket, or a covering for tires. Figure 2 shows a metallic glass tube.

SUBSTANCES RESISTANT TO OXIDATION AS WELL AS TO SULFATE SALTS

As far as metallic glasses are concerned, when they contain chromium, it is extremely easy for their surfaces to form a protective film of oxidation. This formation causes these types of glasses to possess a high resistance to corrosion, and this is particularly true in an environment of oxides. This layer contains chromium combined with hydrogen and oxygen from crystallized water, and it is more effective than is even the oxide film which forms on stainless steel. Possible reasons for this characteristic of high resistance to corrosion are as follows:

1. There is no crystalline boundary corresponding to the complex substances which give rise to discontinuity as well as segregation or liquation.

2. The irregular structure of the glass constitutes an advantage by forming a core for the formation of the oxide layer or film.

3. The atomic concentrations for this sort of metallic compound are high enough to cause the glass involved to form oxides and, thus, to obtain oxide films which are thick and dense.

It really makes no difference what the reason is; metallic glasses are extremely resistant to corrosion. For example, in a case in which one is dealing with a 6% sample of $FeDl_3$ at 60°

for 20 hours, stainless steel is seriously corroded, but metallic glasses are entirely unaffected:

Alloy	Composition	Loss by Weight
430 Stainless Steel	Fe18Cr	87
304 Stainless Steel	Fe20Cr8Ni	6
316 Stainless Steel	Fe18Cr10Ni12Mo	1.5
Metallic Glass	Fe11Cr35Ni12P6B	9

If one is dealing with the subject of exceedingly good characteristics of metallic glasses in the area of resistance to corrosion, it is also possible to explain it by making use of the polarization curve for this type of substance. This type of curve shows that, under various types of fixed voltages or electrical potentials, these sorts of substances exhibit various types of densities of electric flow. The density of electric flow and the rate of corrosion form a directly proportional relationship. From the Figure it can be seen that, under conditions in which the electrical potential is much lower than that for stainless steel, the samples of metallic glasses finally slowed their reaction to the level of inactivity, and it was only under these conditions that this situation was reached, and the peak values recorded their lowest levels. The situation which occurred when four types of materials were changed in an environment in which there was a surrounding voltage in the range of 0-1 volt produced similar results. The largest values for the rate of corrosion of the metallic glasses did not equal one one hundreth that of the rate for 430 stainless steel or one tenth of the rate for 316 stainless steel.

Because of the fact that metallic glass substances are resistant to oxidation as well as resistant to chemical combination with sulfate solutions, there is the possibility of these materials being used in undersea cables, in the steel operational components of naval aircraft, in chemical filters, in reactors, in electrodes as well as in other components used in chemical and industrial operations.

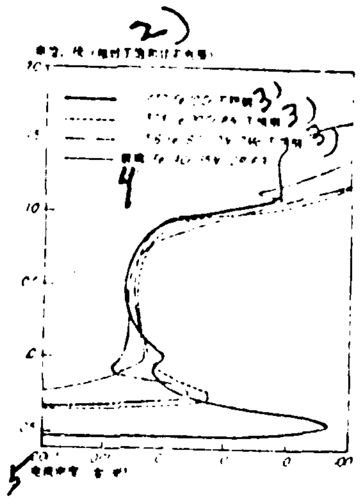


Figure 3. The Relationship Between the Electrical Potential or Voltage and the Rates of Corrosion (that is, the density of electrical flow) for Metallic Glass and Stainless Steel When Exposed to a One Gram Molecular Concentration of H_2SO_4 at 22°C

2. Electrical Potential, ~~in~~ Volts (Corresponding to (illegible) electrode), 3. Stainless Steel, 4. Glass, 5. ~~Density of Electric Flow in Amp.m^{2-}~~. Current density, A/m^2.

SPECIAL MAGNETIC PROPERTIES

Among magnetic iron materials, the ferrous magnetic glasses are the easiest to magnetize; some of them are capable of being magnetized in a field strength of one thousandth of an oursted (that is, ~ 100 milliamperes/m). Before the development of this type of new material, all there was in the way of materials which were easy to magnetize were the skin type alloys (that is, 39-81% Ni, 61-19% Fe) (sic); however, this type of material or alloy was soft and difficult to work.

As far as ferrous metallic glasses are concerned, even though they have irregular structures, they have high capacities for being magnetized. For example, Figure 4 shows the relationship between magnetic saturation and the constituents Fe, Co, and Ni. Among the glasses, the magnetic moment of each transitioning metal atom decreased with an irregular structure, as well as metaloid atoms (for example, boron causes the "floating movement" of the curve to be smaller or the "drift" of the curve to be smaller than it is when one is working with phosphorus.)

Ease of magnetization means that, in the metallic glasses, it is easy for the magnetizing process to move from one neighboring part of the substance involved to another. This fact has already been confirmed by measuring the speed of the magnetizing process from one area to another, and the relationship between this speed and the strength of the field of excitation (that is to say, by measuring the magnitude of the damping coefficient of the magnetizing process from one section of the material to another). A comparison of the results of such measurements for metallic glasses, when compared to similar measurements for several other types of materials, shows that the process of magnetization penetrates through the various sections of a metallic glass with extreme ease relatively speaking.

The possible reasons for this are:

1. The absence of the obstacle of crystalline boundaries.

2. The high coefficient of electrical resistance may cause a dampening of the vertical flow.

3. The absence of multi-directional uniformity as it is found in crystals (although, there is a short-lived multi-directional uniformity).

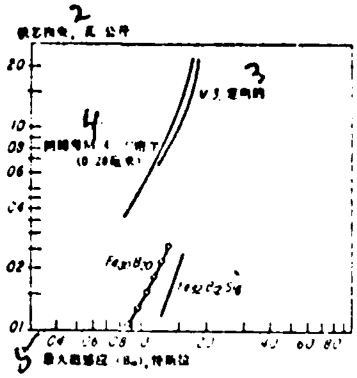


Figure 5. Losses in Magentic Properties of a Transformer with a Thickness of 0.05 cm and a Line Frequency of 60 Hz-sin B as well as the Losses for the Same Type of Transformer When Dealing with Various Types of Magnetism. 2, Ferrous Losses in Watts/kg, 3. Directional, 4. (three characters illegible), 11 mils (0.28 cm), 5. Maximum Induced Magnetization, (three characters illegible).

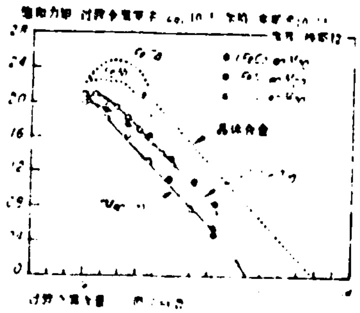


Figure 4. (Words illegible)

Table 2 The Magnetic Characteristics of Metallic Glasses and Several Types of Magnetic Alloys

表2 金属玻璃及几种磁性合金的磁性

材料 2	[illegible] B_s 3 千高斯	[illegible] 4 1.6 千安/米	[illegible] 5 13千高斯 6	16千高斯 6
金属玻璃 7				
$Fe_{40}Ni_{40}P_{14}B_{6}$	7.6	14000	—	—
$Fe_{40}Ni_{38}Mo_{4}B_{18}$	8.8	20000	—	—
$Fe_{80}B_{20}$ 8	15.0	4000	0.22	—
$Fe_{82}B_{10}Si_{8}$ (0.05毫米)	16.3	9000	0.13	0.23
磁性合金 9				
Mo-坡莫合金 10 (79% Ni, 17% Fe)	7.8	35000	—	—
Deltamax (50Ni-50Fe)	16	500	0.77	—
M-1(Fe-3%Si) (0.28毫米) 8	19.7	1000	0.78	1.30
H-2(Fe-3%Si) (0.30毫米) 8	19.7	1000	0.80	1.25

2. Material, 3. Magnetic Saturation Reaction, ~~in Thousands of Gauss~~ MB, 4. The Rate of Direct Magnetic Flow When One is Dealing With 20 oersteds and 1.6 kA/m, 5. Magnetic Losses When One is Dealing With 60 Hz-sin B in Watts/kg, 6. 13 Thousand Gauss, 6. 16 Thousand Gauss, 7. Metallic Glasses, 8. cm 9. Magnetic Alloys, 10. Skin Alloy.

Damping	Damping Coefficient of the Magnetic Domain Boundary Resistance in dynes.sec/mm^3.
Ni-Fe Glass	0.5
Fe Must Be Monocrystalline	26.5
60Ni-40Fe Wire	160.0
Si-Fe Crystal	270.0

The easy mobility of the magnetic domain boundaries indicates that this type of material is possessed of excellent macroscopie magnetism properties (see Table 2). These types of properties add again to the ease of working in this type of material and make these glass ribbons appropriate for use in the construction of electric motors, generators, switches, memory components, recording heads, transducers, and ~~sheilding~~. shielding.

The employment of this type of material as the iron core of transformers has attracted, as a consequence of all these experimental data, the intense attention of many people, and besides the low costs of manufacture, the losses of these types of materials to magnetic hysterisis are small. The magnetic losses for ordinary materials and several types of these ferromagnetic glasses can be found in Figure 5.